Guest Editorial
Optical Wireless Communications

Over the last two decades, wireless communications has gained enormous popularity, offering attractive options for many personal and organizational communication needs due to major intrinsic characteristics such as flexibility, cost effectiveness, and mobility.

Two transmission techniques for wireless communications have been deployed so far; *Radio Frequency (RF)* and *Optical Communications*. While the vast majority of research efforts so far have been dedicated to RF wireless communications, there is a rapidly growing interest in Optical Wireless Communications (OWC) due to intrinsic advantages such as extremely high data rates, inherent security, and licence-free operation. However, OWC also poses several challenges that have to be overcome before widespread deployment of OWC systems is possible. As a consequence, the field of OWC promises enormous opportunities for basic and applied research and development.

Thisspecial issue is an attempt to capture the current state of the art in OWC and to open up new avenues for research in this area.

Research Challenges in Indoor and Outdoor Optical Wireless Systems

Optical wireless systems can be classified into long and short range systems, according to the distance between the transmitter and receiver. Long range systems are used for outdoor optical wireless, while short range systems can be applied for both outdoor and indoor environments. Indoor and outdoor propagation environments are inherently different from each other and pose unique challenges which need to be carefully taken into account for optical wireless system design.

Early research in OWC has focused on design issues related to indoor infrared wireless technologies. These systems are characterized by smaller distances and are free from major outdoor environmental degradations such as fog, rain, snow, and mist. The loss in the indoor link iscaused only by the free space loss. There are two indoor optical wireless transmission techniques: Direct line of sight and diffuse. The direct line of sight configuration has superior power efficiency, low multipath dispersion, and lower path loss and can achieve higher transmission rates. The drawback of this configuration is that it suffers from shadowing and a concern for eye safety that limits the average transmitter power, hence affecting overall power efficiency. On the other hand, the diffuse configuration does not require the alignment of transmitter and receiver and as a result is robust against shadowing and easy to use allowing more mobility. The diffuse system, however, suffers from higher path loss and requires higher transmitter power levels and larger size photo-detecting area at the receivers. It also suffers from multipath dispersion, which occurs when the transmitted signal follows different paths due to its reflection by the ceiling, walls, and other objects on its way to the receiver. The multipath propagation of diffuse systems gives rise to intersymbol interference which becomes critical at higher data rate.

Advances in performance enhancement research on indoor systems have led to novel techniques including hybrid diffuse/line-of-sight (LOS) and hybrid infrared/radio systems. Indoor systems are suitable for in-office and in-home local area networks (LANs). An indoor optical wireless network comprises a number of cells, where each cell is served by one base station and a group of computing hosts. The indoor cells, in this regime, are supported by a fast backbone infrastructure which is typically based on fiber optics. The distinct properties of the indoor optical wireless channel can add to the 4G and beyond vision, with the possibility of a future terminal having a number of interfaces, both radio and optical. Future wireless standards offer a good opportunity for the wider adoption of indoor OWC. In particular, as 4G and beyond networks will be highly heterogeneous, indoor OWC based air interfaces can be incorporated into terminals in addition to the conventional RF based ones. Considerable work is still needed to fully exploit the clear advantages of the optical solutions, as well as developing low-cost subsystems and components to implement them. Other challenges in designing an indoor optical wireless system include the pulse shape of the received signal, permissible transmitted power considering the concern for eye safety, shadowing effects, and background interference.

Outdoor OWC has been around as long as the laser itself and is also commonly referred to as free-space optical communication. These systems are categorized as satellite-based and terrestrial-based free-space links. The current market of satellite-based free-space optical links is emerging mainly in the area of inter-satellite links. The terrestrial-based links are used as a last or first mile access by bringing broadband to home as well as a high bandwidth bridge between LANs, metropolitan area networks (MANs), and wide-area networks (WANs).

Optical links for connecting LANs between high-rise buildings in the metropolitan areas are commercially available today for a distance of about 1 km. An added benefit from the use of terrestrial short-range outdoor OWC is relief from the regulatory, licensing, and frequency management and coordination issues encountered in implementing RF systems. Other than the safety issues and regulations involving human exposure, which largely disappear with the use of inherently eye-safe wavelengths, OWC is not currently subject to regulation or control by any frequency management organization. Furthermore, since they are typically implemented as a narrow

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beam point-to-point connection, there is little likelihood of interference.

There are several sources of path loss, scattering and interference, which degrade the performance of outdoor optical wireless systems. Free space loss represents the portion of power lost to space. Clear air similarly absorbs another portion. Scattering and refraction constitute the attenuation resulting from water droplets and other particulates. Scintillation is a scattering effect resulting from solar energy.Geometrical and pointing losses also affect the performance of optical wireless systems. By using excess optical power margins to mitigate the fading loss, this problem can be reduced. Receiver sensitivity largely affects system performance, which is however an artificial issue imposed by the use of certain detectors. Finally, light interference is one of the most studied degradation factors of optical wireless systems. Generally, outdoor optical wireless systems are inherently more prone to path loss. While indoor systems are predominantly affected by free space loss, outdoor systems are also exposed to atmospheric conditions such as fog, snow and rain as well as to other particulates, such as partially-burned hydrocarbons, sand and dust. The amount and type of absorption, scattering and interference depend on the optical wavelengths used for communication. For example, unlike visible light, terrestrial communication with high-frequency ultraviolet light experiences very little interference caused by solar radiation, because much of the sunlight at those frequencies is absorbed by the atmosphere and never reaches ground level.

This special issue includes a collection of 19 papers which will undoubtedly contribute to the solution of some of the above-mentioned problems which hamper the widespread deployment of OWC systems. The papers can be grouped into the areas: a) Channel Modeling, b) Modulation, Coding and Signal Processing Techniques, c) Transmitter and Receiver Design, Experimental Demonstrations and Tests, and d) Hybrid RF/OWC Systems.

Channel Modeling

The first two papers deal with the channel modeling of OWC systems.

Hajjarian, Kavehrad and Fadlullah, in "Analysis of Wireless Optical Communications Feasibility in Presence of Clouds Using Markov Chains" investigate the possibility of simplifying the Monte-Carlo Ray Tracing (MCRT) techniques, used in the past to analyze the channel behavior. A direct extraction of state transition matrices is used, associated with standard Markov modeling from the MCRT computer simulations programs.

The paper "Modeling of Non-Line-of-Sight Ultraviolet Scattering Channels for Communication" by Ding, Chen, Majumdar, Sadler and Xu, presents a stochastic non-line-of-sight (NLOS) ultraviolet (UV) communication channel model, which is used to study the characteristics of NLOS UV scattering channels, including path loss and channel bandwidth for a variety of scattering conditions, source wavelength, transmitter and receiver optical pointing geometries, and range.

Modulation, Coding, and Signal Processing Techniques

The next seven papers are related to modulation, coding and signal processing techniques in OWC systems.

In the paper, "Performance Analysis of Space Time Block Coding Techniques for Indoor Optical Wireless Systems", byNtogari, Kamalakis and Sphicopoulos, the performance of diffuse optical wireless systems, employing Space Time Block Coding (STBC), is investigated, taking into account the indoor channel impulse response and the characteristics of ambient light and thermal noise at the receiver.

Farid and Hranilovic in "Channel Capacity and Non-Uniform Signalling for Free-Space Optical Intensity Channels", consider the design of capacity-approaching, non-uniform optical intensity signalling in the presence of average and peak amplitude constraints. In this work, a simple expression for a capacity-approaching distribution is derived via source entropy maximization.

Brandenburg and Liu in the paper "Optical Signal Detection in the Turbulent Atmosphere using p-i-n Photodiodes" study the performance of signal detection for intensity modulated direct detection optical communications systems over turbulent channels, considering statistics of photoelectron count in p-i-n photodiodes.

The paper "Analysis of Generalized Optical Orthogonal Codes in Optical Wireless Local Area Networks" by Khazraei and Pakravan, analyzes the performance of Generalized Optical Orthogonal Codes (GOOC) in optical wireless local area networks. A mathematical model is developed to study the performance of several classes of GOOC for indoor optical wireless applications.

In "Performance Analysis of Quantum Cryptography Protocols in Optical Earth-Satellite and Intersatellite Links" by Moli-Sanchez, Rodriguez-Alonso and Seco-Granados, the authors analyze the feasibility of performing Quantum Key Distribution (QKD), in earth-satellite up and downlinks and in intersatellite links, with two quantum cryptography protocols: BB84 and SARG04 and with two implementation options: with and without decoy states.

Reinhardt, Jaruwatanadilok, Kuga and Ishimaru present in the paper "Improving Bit-Error-Rate performance of the Free-Space Optical Communications System with Channel Estimation Based on Radiative Transfer Theory," a method for the estimation of the atmospheric channel impulse response function, which governs the optical intensity propagation, is presented.

The paper "OWLS: A Ten-Year History in Optical Wireless Links for Intra-Satellite Communications" by Arruego, Guerrero, Rodríguez, Martinez-Oter, Jiménez, Domínguez, Martín-Ortega, de Mingo, Rivas, Apéstigue, Sanchez, Iglesias, Álvarez, Gallego, Azcue, de Galarreta, Martín, Álvarez-Herrero, Díaz Michelena, Martín, Tamayo, Reina, Gutierrez, Sabau, and Torres, summarizes ten years of developments in the area of OWLS, ranging from basic optoelectronic parts and front-end electronics to different in-orbit demonstrations, that will lead to the launch ofa completely wireless satellite at the beginning of 2010.Furthermore, technological developments necessary for future breakthroughs in this field are outlined.

Transmitter and Receiver Design, Experimental Demonstrations and Tests

The next seven papers deal with the transmitter and receiver design, experimental demonstrations and tests.

The paper "Multi-Transceiver Optical Wireless Spherical Structures for MANETs", by Niasari, Bilgi, Yuksel and Hella, studies a multi-transceiver spherical OWC structure as a basic building block for enabling optical spectrum in mobile ad-hoc networking. Optimal designs of such multi-transceiver subsystems are proposed, in order to maximize the coverage and to minimize the crosstalk among neighboring transceivers.

The next paper "On the SIR of a Cellular Infrared Optical Wireless System for an Aircraft" by Dimitrov, Mesleh, Haas, Cappitelli, Olbert, and Bassow, develops path loss models of an infrared optical wireless transmission inside the cabin of an aircraft. Furthermore, a cellular network in the aircraft is considered and signal-to-interference ratio (SIR) is evaluated.

The paper "1.28 Terabit/s (32x40 Gbit/s) WDM Transmission System for Free Space Optical Communications" by Ciarammella, Arimoto, Contestabile, Presi, D'Errico, Guarino, and Matsumoto, proposes a novel optical wireless system. This system encompasses a pair of novel terminals, which allow direct and transparent optical connection to common mode single fibers and include a dedicated electronic control unit that effectively tracks the signal beam wandering due to atmospheric turbulence and mechanical vibrations.

In the paper "Design and Implementation of Optical Wireless Communications with Optically Powered Smart Dust Motes" by O'Brien, Liu, Faulkner, Sivathasan, Yuan, Collins, and Elston, the authors report the design and implementation of a communications system that uses a base station to communicate with, and power, smart dust motes, over ranges of tens of meters.

Zeng, O'Brien and Minh in "High Data Rate Multiple Input Multiple Output (MIMO) Optical Wireless Communications Using White LED Lighting," investigate non-imaging and imaging MIMO approaches: a non-imaging optical MIMO system does not perform properly at all receiver positions due to symmetry, but an imaging based system can operate under all foreseeable circumstances.

In the paper "Adaptive Mobile Line Strip Multibeam MC-CDMA Optical Wireless System Employing Imaging Detection in a Real Indoor Environment," by Alsaadi and Elmirghani, the techniques of transmit power adaptation, imaging reception, and Multicarrier Code Division Multiple Access (MC-CDMA) are introduced for use in optical wireless systems. It is shown that these techniques offer a significant performance improvement in the presence of directive noise, multipath propagation, mobility and shadowing.

"Wireless Optical CDMA LAN: Digital Implementation Analysis" is the last paper of this group, by Ghaffari, Matinfarand Salehi. It investigates a digital design of a wireless optical CDMA system based on generalized optical orthogonal codes. A prototype is described and the main aspects of an implementation of the system are highlighted.

Hybrid RF/OWC Systems

The last three papers belong to the category of hybrid RF/OWC systems.

In the paper "Weather Effects Optimum RF Link on HybridFSO/RF Communication Link" by Nadeem, Kvicera, Awan, Leitgeb, Muhammad, and Kandus, the authors investigate the performance of hybrid FSO/GHz systems.The effects of fog, rain and snow on FSO/GHz hybrid network are studied so that GHz frequencies with best complementary behavior can be selected as a back up link.

The paper "Soft-Switching Hybrid FSO/RF Links Using Short-Length Raptor Codes: Design and Implementation" by Zhang,Hranilovic, and Shi, proposes the application of Raptor codes in hybrid FSO/RF links. A set of short-length Raptor codes (k = 16 to 1024) are presented which are amenable to high-speed implementation and a practical Raptor encoder and decoder are implemented in FPGA and shown to support a 714 Mbps data rate with a low 97 mW power consumption and 26360 gate circuit scale.

Finally, Letzepis, Nguyen, Fàbregas, and Cowley in "Outage Analysis of the Hybrid Free-Space Optical and Radio Frequency Channel," study the fundamental limits of the hybrid FSO/RF channel for various scintillation distributions. For the case when perfect channel state information is known at both the receiver and transmitter the optimal power allocation strategy that minimizes the outage probability subject to peak and average power constraints is derived.

Acknowledgments

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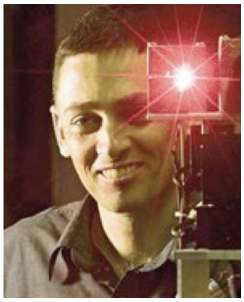

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